DIMENSIONAL STABILITY OF PARTICLEBOARD BINDED WITH DIFFERENT PERCENTAGES OF STARCH AND ADHESIVES

Kang-Chiang Liew[1] and Yu-Feng Tan[1]

[1]Faculty of Science and Natural Resources, Forestry Complex, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.
Email: liewkc@ums.edu.my, Web Page: http://www.ums.edu.my

Keywords: Dimensional stability, particleboard, starch, adhesive

Abstract

The downgrade of synthetic polymers due to health concerns regarding formaldehyde emission has pushed the society to turn their preferences to bio-based adhesives which were known to derived from natural resources. This study was carried out to evaluate the effect of different percentages of starch on the dimensional stability properties of particleboard produced and the relationship between different percentages of starch with different adhesive content on the dimensional stability of particleboard produced from these adhesive as a binder. The starch-based adhesive was produced by mixing glycerol, water, and vinegar with different percentages of starch (10%, 15%, and 20% based on 295 g) heated on hot plate. Subsequently, different starch-based and UF (control) adhesive content (20%, 25%, and 30%) were mixed with wood particles, mat formed, pre-pressed, hot-pressed and left to condition before cut into sizes for water absorption (WA) and thickness swelling (TS) test. Through this study, significant difference at $p \leq 0.05$ was detected in WA when the percentage of starch was increased by 5% while, on the other hand, no difference at $p \leq 0.05$ for TS. Also, insignificant difference at $p \leq 0.05$ were shown in WA and TS when the adhesive content was 5% different. In a nutshell, different percentages of starch used will only affect the WA of particleboard. There was no effect in WA and TS with different amount of adhesive content used in this study.

1. Introduction

Wood adhesives were mainly produced from petroleum-based polymer such as phenol formaldehyde, urea formaldehyde, and melamine formaldehyde, showing high mechanically and physically stable properties. However, the increasing awareness of these synthetic resins that pose threat to humans' health and polluted the environment have led to the reduction in their usage.

Therefore, bio-based adhesive has become one of the substitutes in which this biodegradable polymer is derived from natural resources such as starch, protein, and cellulose. Many studies have been carried out by adding different enhancers to these polymer materials such as nano particles were added to starch-based wood adhesive to improve bonding strength and water resistance [1] and sodium dodecyl sulfate to improve the performance of this adhesive [2].

Moreover, the performance of bio-based adhesive is often questioned with their comparison to synthetic adhesives especially the poor water resistance characteristics of bio-based adhesives which lead to short lifespan of wood-based panel. Thus, special formulated bio-based adhesive which includes starch, glycerol, vinegar, and water will be incorporated in this study to evaluate the possibility of using different concentrations of starch in bio-adhesives from the aspects of physical and dimensional stability of particleboards.

This study aimed to evaluate the effect of different percentages of starch on the physical and dimensional stability properties of particleboard produced. Urea formaldehyde (UF) was used as a control in this study.

2. Materials and Methods

2.1. Raw material and adhesive preparation

Small logs were chipped, flaked and screened to particles with length of 0.5-2.0 mm. The particles were oven-dried at 70°C for 24 hours to obtain moisture content at approximately 2-4%.

Tapioca starch, vinegar, glycerol, and water were used to formulate starch-based adhesive. Batches of small amount of starch-based adhesive were produced to ensure that the adhesive was well cooked. Starch with 10%, 15%, and 20% (based on 295 g) were incorporated in the mixtures before being heated on hot plate at 70-80°C for about 20 minutes and stirred constantly. Brookfield Viscometer was used to measure the viscosity of each starch-based adhesives produced. Urea formaldehyde resin was used as a control in this study.

2.2 Particleboard manufacture

The targeted board density was 600 kg/m^3. The particles were mixed with adhesive of different percentages which were 20%, 25% and 30%. The mixture was then placed into a mat forming frame measuring (300 x 300 x 10) mm. Subsequently, hot-pressing at 165°C, 135 MPa for 5 mins. The board was then left to cool and conditioned for 72 hours with relative humidity of 65 % at 20 ± 2°C. These methods were repeated for different percentages of starch (10S, 15S, and 20S) and adhesive (20%, 25% and 30%) for each board.

2.3 Testing method

a) Water absorption (WA)

The weight of each test piece was measured before immersion in water of 20 ± 1°C horizontally about 3 cm below the water surface for 24 hours. After 24 hours, test pieces were taken out and excessive water was wiped off before measuring the weight again. The weight of test piece before and after immersion was recorded and the percentage of water absorption was calculated according to Equation 1 [3].

$$\text{Water Absorption (\%)} = \frac{Weight\ (after\, submersion) - Weight(before\, submersion)}{Weight\ (before\, submersion)} \text{ X } 100\ \% \qquad (1)$$

b) Thickness swelling (TS)

The thickness in the centre of test piece were measured to the nearest 0.05 mm with a micrometre. Then, the test pieces were immersed in water of 20 ± 1°C horizontally about 3 cm below the water surface for 24 hours. After 24 hours, test pieces were taken out and excessive water was wiped off before measuring the thickness again in the same manner as before. The swelling in thickness of test pieces after immersion in water were calculated based on Equation 2 [3].

$$\text{Thickness Swelling (\%)} = \frac{t_2 - t_1}{t_1} \times 100\ \% \tag{2}$$

where, t_1: thickness (mm) before immersion in water.
t_2: thickness (mm) after immersion in water.

2.4 Data analysis

The data obtained from this study were analysed according to WA and TS between different percentages of starch content in starch-based adhesives and urea-formaldehyde with different percentages of adhesive content in particleboard. One-way between groups ANOVA with post-hoc multiple comparison was used to obtain the Least Significant Different (LSD) for different percentages of starch and adhesive separately.

3. Results and Discussion

Table 1 shows the comparison and analysis with mean and standard deviation of WA and TS between the starch-based adhesive and urea formaldehyde as a control, as well as different amount of adhesive in the particleboard produced.

Table 1. Comparison and analysis with mean and standard deviation of WA and TS for different types of starch-based adhesive with different percentages of adhesive content in particleboard.

Types of adhesive	% of adhesive	Properties	
		WA (%)	TS (%)
UF	20	$61.38^{a}_{x} \pm (12.14)$	$12.06^{a}_{x} \pm (1.67)$
	25	$74.02^{a}_{x} \pm (14.68)$	$11.51^{a}_{x} \pm (2.83)$
	30	$37.53^{a}_{x} \pm (8.05)$	$7.58^{a}_{x} \pm (2.24)$
10S	20	$169.99^{b}_{x} \pm (8.64)$	$84.42^{b}_{x} \pm (9.40)$
	25	$166.97^{b}_{x} \pm (11.65)$	$71.57^{b}_{x} \pm (7.66)$
	30	$172.85^{b}_{x} \pm (14.01)$	$76.14^{b}_{x} \pm (5.98)$
15S	20	$157.39^{c}_{x} \pm (13.15)$	$82.39^{b}_{x} \pm (6.99)$
	25	$154.47^{c}_{x} \pm (9.08)$	$78.49^{b}_{x} \pm (7.88)$
	30	$149.09^{c}_{x} \pm (6.54)$	$71.18^{b}_{x} \pm (5.69)$
20S	20	$135.48^{d}_{x} \pm (12.96)$	$80.31^{b}_{x} \pm (6.40)$
	25	$157.34^{d}_{x} \pm (9.91)$	$78.75^{b}_{x} \pm (7.23)$
	30	$125.55^{d}_{x} \pm (11.03)$	$75.01^{b}_{x} \pm (9.42)$

- The number that are not in parentheses is the mean; The number in parentheses is the standard deviation.
- Value in the same column with different alphabets a, b, c, d within a column for different types of adhesive in each percentage of adhesive content for each test indicates significance at $p \leq 0.05$ in Least Significant Difference (LSD).
- Value in the same column with different alphabets x, y within a column for different percentages of adhesive content in each type of adhesive for each test indicates significance at $p \leq 0.05$ in Least Significant Difference (LSD).

3.1 Water absorption (WA)

Figure 1 shows the starch-based adhesive gives higher mean value as compared to urea formaldehyde at different percentages of adhesive added in the particleboard. In the comparison of starch-based adhesives only, adhesive with 10% of starch has the highest mean value. WA of 10S with 30% amount of adhesive content have highest recorded mean value of 172.85%. Apart from that, 20S has the overall lowest mean value of WA compared to 10S and 15S. The lowest mean value recorded was 125.55% for 20S with 30% amount of adhesive content.

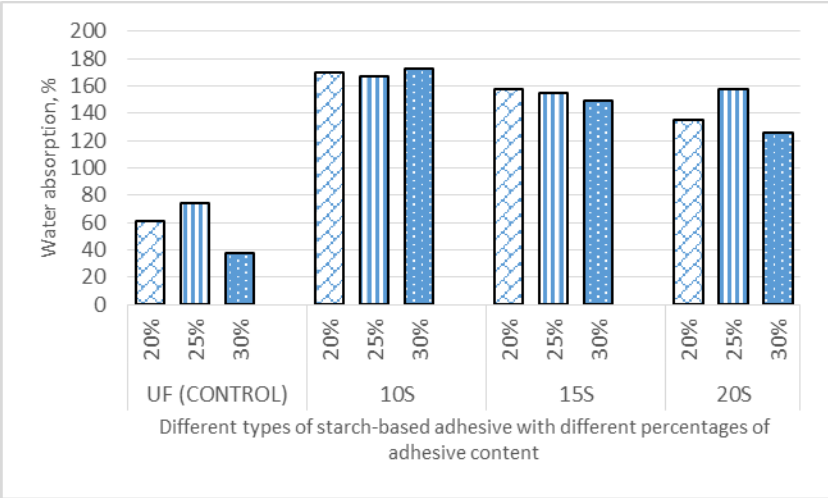

Figure 1. Average water absorption (%) for particleboards binded using different percentages of adhesive content (20%, 25%, and 30%) prepared from adhesive with different percentages of starch incorporated (10S, 15S, and 20S).

Besides, from the One Way ANOVA shown in Table 1, it can be observed that there was significant difference at $p \leq 0.05$ between starch-based adhesives and urea formaldehyde as a control. Significant difference also can be seen between the starch-based adhesives where 10S, 15S and 20S show significant effect among each other. This means that there was effect shown when the percentages of starch in the starch-based adhesive changes. On the other hand, the different amount of adhesive content (20%, 25%, and 30%) in the particleboard shows that there was no difference at $p \leq 0.05$. This indicate that there was no effect given by the difference of 5% in between the amount of adhesive content in the WA.

The water absorptivity of starch-based adhesive could be explained by the hydrophilic nature of starch. Starch molecule consists of two main functional groups which are the OH group and C-O-C bond. The OH group is what responsible for the high affinity towards water that caused many of the problem of WA as this functional group is susceptible to substitution reaction. Besides, the C-O-C bond present in the molecule of starch also susceptible to chain breakage [4]. The weak hydrogen bonds in starch causes hydrogen groups to break down easily and form another hydrogen bonds with water molecules [5]. This has resulted in poor water resistance of the particleboard. Therefore, this could explain why different percentages of starch incorporated in starch-based adhesive will affect the end-result. By increasing the amount of starch in starch-based adhesive, more hydrogen bonds were breaking apart and allows for more water molecules substitution.

Apart from that, particleboard that uses urea formaldehyde have lower mean value of WA than starch-based adhesive. This could be explained that the urea formaldehyde resin has stronger and more sustainable cohesive and binding force [6]. Moreover, better interfacial contact between fibre-matrix bonding in urea formaldehyde results in good bonding properties which then cover the parenchyma tissues from absorbing water [7].

3.2 Thickness swelling (TS)

Figure 2 shows 10S with 20% amount of adhesive content gave highest mean value which was 84.42% of TS among different starch-based adhesives. Statistical results in Table 1 shows that there was significant difference at $p \leq 0.05$ between urea formaldehyde (control) and starch-based adhesive. However, there were no difference at $p \leq 0.05$ between different types of adhesive and different amount of adhesive content. This indicates that there was no significant effect in the thickness swelling of particleboard manufactured from 10S, 15S, and 20S of starch with 20%, 25%, and 30% of adhesive content in the board.

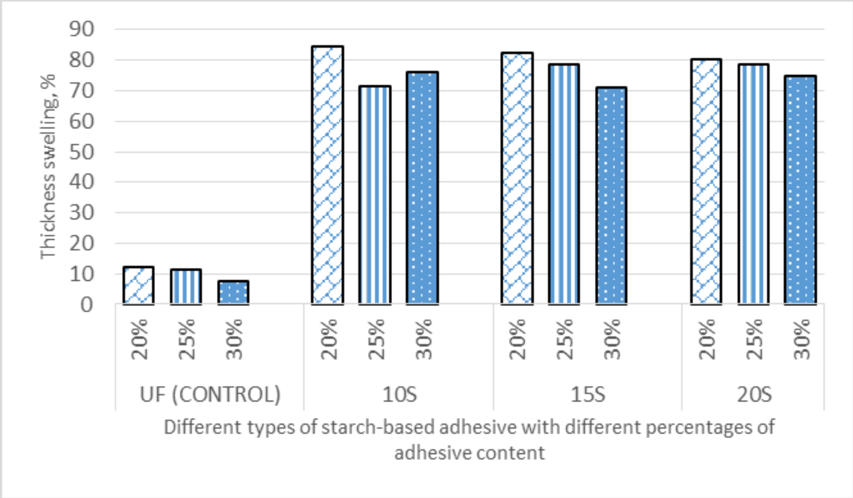

Figure 2. Average thickness swelling (%) for particleboards binded using different percentages of adhesive content (20%, 25%, and 30%) prepared from adhesive with different percentages of starch incorporated (10S, 15S, and 20S).

Urea formaldehyde shows better dimensional stability which might be due to the strong urea formaldehyde resin properties with stable adhesive forces [8]. This provides better water resistance than starch-based adhesive. The sufficient bonding strength with reduction in internal force generated by water is also one of the reason urea formaldehyde perform better than starch-based adhesive [6].

In the meantime, TS of composite material was influenced by few factors such as the quality and distribution of adhesive, moisture content, compatibility, and chemical composition of the furnish [9]. In this case, there were possibilities that the starch-based adhesive produced has poor dispersion when mix with particleboard. Besides, dissolution of the material that happened due to the weak bonding between neighbouring polymer causes the swollen of material [4].

4. Conclusions

In a nutshell, significant effect was detected when the amount of starch increases by 5% in WA. The highest mean value recorded was 10S in which the value ranges from 166.97% to 175.85. As for TS test, no effect was observed with different percentages of starch (10S, 15S, and 20S) used in the starch-based adhesive.

Apart from that, the difference in adhesive content (20%, 25%, and 30%) incorporated in the making of particleboard also give no effect in both WA and TS test. In short, starch-based adhesives which have higher value of WA and TS as compared to UF were higher. This indicate that more water was being absorbed which gave property of poor water resistance. These results are especially not favourable in the wood industry as poor water resistance of wood will cause more problem to the performance of wood. The presence of starch is what responsible for the high-water absorptivity and thickness swelling of particleboard.

References

[1] Z. Gu, Z. Wang, Y. Hong, L. Cheng, and Z. Li. Bonding strength and water resistance of starch-based wood adhesive improved by silica nanoparticles. *Carbohydrate Polymers,* 86: 72-76, 2011.

[2] Z. Li, J. Wang, L. Cheng, Z. Gu, Y. Hong, and A. Kowalczyk. Improving the performance of starch-based wood adhesive by using sodium dodecyl sulfate. *Carbohydrate Polymers,* 99: 579–583, 2014.

[3] Japanese Industrial Standard (JIS). *JIS A 5908 – Particleboards*. Japanese Standard Association, Tokyo. 2003.

[4] P. Oakley. Reducing the water absorption of thermoplastic starch processed by extrusion. Degree of Master of Applied Science. Thesis. University of Toronto, Canada. 2010.

[5] V. Hemmila, J. Trischler, and D. Sandberg. Bio-based adhesives for the wood industry – an opportunity for the future? *Pro Ligno,* 9: 118-125, 2013.

[6] H.P.S. Abdul Khalil, M. Jawaid, and A. Abu Bakar. Woven hybrid composites: water absorption and thickness swelling behaviours. *BioResources,* 6: 1043-1052, 2011.

[7] C.K. Abdullah, M. Jawaid, H.P.S. Abdul Khalil, and Hadiyane. Oil palm trunk polymer composite: morphology, water absorption, and thickness swelling behaviours. *BioResources,* 7: 2948-2959, 2012.

[8] N. Malhotra, K. Sheikh, and S. Rani. A review on mechanical characterization of natural fiber reinforced polymer composites. *Journal of Engineering Research and Studies*, 3:75-80, 2012.

[9] A.H. Iswanto, I. Azhar, Ir. Supriyanto and A. Susilowati. Effect of resin type, pressing temperature and time on particleboard properties made from sorghum bagasse. *Agriculture, Forestry and Fisheries,* 3: 62-66, 2014.